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Review

# Degradation of Tibetan grasslands: Consequences for carbon and nutrient cycles

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ABSTRACT

The Tibetan Plateau hosts the world's largest alpine pastoral ecosystems, dominated by the endemic sedges *Kobresia pygmaea* and *Kobresia humilis*. Owing to the very harsh environment and also to soil nitrogen (N) and phosphorus (P) limitations, these pastoral ecosystems are very sensitive to disturbances (e.g. anthropogenic activities and climate change) and recover extremely slowly. Overgrazing on the Tibetan Plateau has caused severe degradation of vegetation and soils in the last 30–50 years. For the first time, for *Kobresia* pastures in Tibetan Plateau, we have summarized and generalized the consequences of pasture degradation for soil organic carbon (SOC) and nutrient (N, P) stocks, and evaluated the main biotic and abiotic mechanisms of their loss. Based on 44 literature studies as well as own data, we demonstrated that 42% of SOC stocks were lost, relative to non-degraded pastures. These SOC losses are similar to the decreases in N stocks (-33%), and aboveground (-42%) and belowground (-45%) plant biomass. Although P losses are lower (-17%), its precipitation reduces its availability for plants. These losses are in fact underestimates, since undisturbed natural sites no longer exist on the Tibetan Plateau. The losses are much higher in the upper 10 cm and in some areas extend to complete removal of soil cover. This has dramatic repercussions for local livestock, human populations and river pollution. While some rehabilitation projects have shown positive outcomes, the complete recovery of degraded pastures (e.g. soil fertility, ecosystem stability) is infeasible, because of very slow pedogenic processes, slow vegetation restoration, as well as continuously increasing anthropogenic pressure and climate change. Considering the rapid losses of SOC and nutrients, and the very slow recovery potential, Tibetan pastures in some regions may disappear in the next few decades without proper and effective recovery strategies.

## 1. Introduction

The *Kobresia* pastures, commonly known as "alpine meadow", cover the southeastern quarter of the Tibetan Highlands and form the world's largest alpine pastoral ecosystem (Babel et al., 2014). Several major Asian rivers, such as the Huang He, Salween River, Yangtze River, Mekong River etc., originate on the Tibetan Plateau and flow through *Kobresia* pastures (Fig. 1). These rivers collectively constitute the main water resource for billions of people in the adjacent regions of southeastern Asia (Pomeranz et al., 2013). The *Kobresia* pastures provide important grazing grounds for livestock (i.e. yaks, sheep and goats) and thus ensure the livelihood of the Tibetan herders (Harris, 2010). Approximately 4.0% of the world's grassland soil carbon (C) is stored in soils under Tibetan pastures (ca. 10.7 Pg C; Ni, 2002). Around 920 Tg nitrogen (N) is preserved in the Tibetan pasture soils, which represents 0.7-1.0% of total global N storage (Tian et al., 2006) and is required for sufficient forage production. Consequently, Tibetan pastures are of considerable importance to livestock productivity, Tibetan herders (ca. 5 million), nutrient cycling and ecosystem stability.

The Tibetan pastures are developed over centuries in extreme environments: low mean annual temperatures (below 0 °C, Frauenfeld et al., 2005), low annual mean precipitation (~437 mm, Xu et al., 2008), very high solar radiation (Liu et al., 2012), very short plant growing season (~3.5 months, Leonard and Crawford, 2002), strong erosion by wind and water (48 t $ha^{-1}$ $yr^{-1}$, Yan et al., 2000), very limited nutrients (e.g. N and phosphorus (P); Li et al., 2014a), very shallow soil profiles (~30–50 cm, Chang et al., 2014) and low air pressure and $CO_2$ concentration. These harsh conditions make the

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